DAIRY PRODUCTS RESEARCH CENTRE
MOOREPARK

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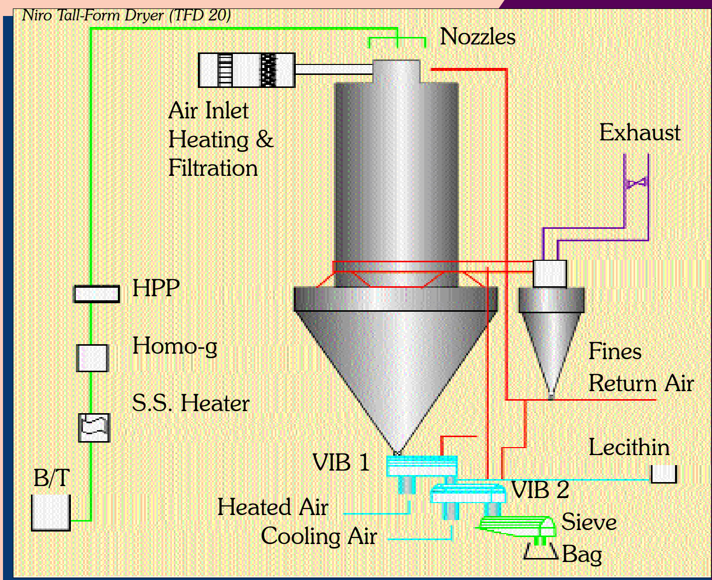
Ingredient Development using a Pilot-Scale Tall-Form Spray Drier

Dr. P.M. Kelly

Using the technically advanced Tall-Form drier pilot plant at Moorepark, correlations were established between process parameters and the physio-chemical properties of powders containing varying fat (20% to 80%) and protein contents. As a result it is now possible to confidently pre-select appropiate processing parameters during the spray drying of ingredients to acheive the required end product specifications.



Teagasc
The Science of Farming and Food

Ingredient Development using a Pilot-Scale Tall-Form Spray Drier

Armis No. 4429

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Summary and Conclusions

The unique pattern of milk production in Ireland along with other factors has contributed to the development of an extensive milk powder manufacturing sector. Continual commitment to quality and product/process development has enabled the industry to move towards differentiating its range of products in order to address the specific ingredient needs of its customer. Thus, a core expertise in milk powder manufacture has given rise to a capability by which processes may be adapted readily in order to meet a range of end-product specifications. One limitation, however, is that much of the existing dehydration technology in the dairy industry installed during a 25-year period, 1965-1990, is limited in flexibility in terms of accomplishing the drying of more challenging ingredient products.

A number of factors within the past 10 years has increased the profile of the dairy processing sector as an important source of functional ingredients. Innovative research and development is continuing to open up more and more opportunities. Commercial relationships between international food companies and their ingredient suppliers is developing to the point where a 'one-stop shop' approach provides a platform for the introduction of innovative solutions; reliance on technical marketing support, and dependability in terms of consistent quality and delivery. The growing importance of this sector has been recognised in the recommendations contained within the government-commissioned Report by the Expert Group on the Food Industry which was published in the early '90s. Infrastructure support has been reinforced in the meantime by substantial national and EU investment in state-of-the-art pilot scale ingredient processing and dehydration facilities installed at the Teagasc/dairy co-operative joint-venture company, Moorepark Technology Ltd (MTL) which was set up as a commercial entity on the Moorepark campus at the end of 1993.

The main objectives of the project were to establish relationships between process variables and product physicochemical/functional characteristics in the course of processing and drying new dairy-based ingredients such as high-fat and protein-rich products in regular and agglomerated forms. By establishing processing protocols, R&D users of the ingredient drying facilities of Moorepark Technology Ltd may be able to predict the process variables necessary for desired end-product specifications to be achieved, and thus make experimentation more efficient and cost effective, as well as facilitate small scale production runs and sample preparation for market development purposes. Particular emphasis was placed on the development of high fat cream and fat-filled powders, flavour-delivery systems and protein-enriched ingredients.

The main conclusions and achievements

The major achievement of this project is that it is now possible to confidently select the appropriate processing conditions during the spray drying of ingredients in order to attain desired end-product specifications. Based on the use of the newly-installed Tall-form drier, the project succeeded in correlating the effects of process parameters of this technically-advanced pilot plant with the physicochemical properties of powders containing varying fat (20-80%) and protein contents. In general, the physicochemical characteristics of fat-filled and cream-filled powders with similar fat contents were similar except for higher solubility index values (range 0.1-0.6) in the case of the former particularly in the range 26-28% fat. Furthermore, the free fat content of powders may now be controlled much more precisely using an appropriate combination of total fat, atomiser nozzle selection and post-drying blending.

The main process/product parameter guidelines and recommendations are presented below:

Atomiser nozzle size

** selection is critical when producing powders to specification, not alone because of the need to control feed rate within the water evaporation rates dictated by the limits of milk drying parameters, but also because of the effects on physicochemical parameters*

Free Fat

** concentration to a higher total solids prior to drying reduces free fat %*
** free fat increases with increasing fat content in the range 26% to 70% fat*
** product reformulation and process rearrangement is necessary to achieve high free fat levels in whole milk powder*

Moisture

** is dependent on the interaction between fat % and inlet temperature*
** is independent of concentrate total solids*

Bulk density

** 94% of the variation in bulk density of cream-filled powders with fat contents ranging from 26% to 70% may be explained by a complex series of relationships between the process parameters: fat content; drier inlet temperature; drier outlet temperature; the interactions between fat and concentrate total solids, concentrate solids and inlet temperature, inlet and outlet temperatures*
** the interaction between atomisation pressure and % fat has a major effect on bulk density of fat-filled powders (R^2 = 0.78)*

Novel process for the manufacture of high-free fat powders

** The process steps involves the preparation of high fat base (concentrate) using cream; standardising with skim milk in order to adjust the fat/dry matter to 70% before concentration (46-48% total solids) and spray drying. The resulting high fat-high free fat powder may be dry-blended with skim milk powder in order to standardise downward the* *fat content to that of whole milk powder i.e. 26% fat. A free-fat level (expressed as a percentage of total fat content) of 82% is obtainable.*

Whey protein concentrates
** drier contribution to the denaturation of WPC during drying is modest relative to that which takes place during other processing stages.*

Milk proteinate
** a novel process for the co-precipitation of casein and whey protein in acid and solubilised forms was developed.*

Commercial Impacts

** A milk protein ingredient was prepared and dried on behalf of a dairy company for evaluation as an ingredient in cream cheese formulations.*

** Parameters were established for the production of agglomerated fat-filled powders with defined coffee stability characteristics on behalf of a client.*

** Spray drying and agglomeration of high protein WPC to satisfy a market specification was successfully accomplished in conjunction with commercial interests. Lecithination of these powders with varying rates of lecithin addition was also achieved.*

** The feasibility of a system for the co-precipitation of casein and whey proteins in a curd form that could be recovered and washed in a modern industrial acid casein processing plant was demonstrated during trials in 1997.*

** Permeate spray drying application was taken up by an interested client.*

** Trials for a dairy company were carried out to dry de-lactosed whey using various carrier ingredients.*

Research and Results

Production of skim milk powder

The principle objective during milk dehydration is reduce moisture content to the point (typically < 4.0% in the case of skim milk powder) where microbial and other chemical activity is immobilised. Powder bulk density is affected by many aspects of the drying process including the composition of the starting material itself. Variations in this property may be of consequence from a packaging point of view, e.g. it may not prove possible to pack the required weight of in a 20 kg sack if a powder were too light or dusty due to a poor bulk density. Solubility index is an indirect measure of the extent to which irreversible changes have occurred to milk protein, particularly casein, during the concentration and drying process. The presence of scorched particles is an indication of overheating of milk/milk powder particles during the drying process which may arise due to 'burn-on', friction effects in the atomiser zone and rotary valves, adherence to drier chambers walls; and depositions around the air distributor.

The following process conditions were investigated as input variables:

preheat temperatures:	*75°C x 15 s; 97.5°C x 15 s; and 120°C x 2 min*
concentrate total solids:	*42, 48.5 and 55 %*
inlet air temperatures:	*170°, 187.5° and 205°C*
nozzle atomiser pressure:	*150, 200 and 250 bar*

On the output side, powder properties monitored included:

moisture content
bulk density
solubility index

In terms of overall quality, all powders were acceptable with ***solubility index*** *values < 0.1 ml, and the absence of* ***scorched particles****. Particle size distribution was within the range 45-150* µ.

Bulk densities of 0.70-0.80 g/ml were obtained by drying of skim milk concentrates containing 42% *total solids*, irrespective of the preheat temperature (75°C or 120°C) used. However, at the higher concentrate solids of 55%, *bulk densities* were reduced somewhat by increasing the preheat temperature from 75°C (*bulk density*: 0.63-0.79) to 120°C (*bulk density*: 0.58-0.76). In the latter case, drying at the higher air inlet temperature of 205°C appeared to be a contributory factor.

As expected, powder *moisture* levels ex-drier chamber increased as outlet temperatures decreased. Generally it is accepted that the powder *moisture content* at the point of discharge from the drier chamber in 2-stage drying plants should be approx. 5-6% before final drying in the external fluidised beds. *A moisture content (ex-chamber) of 5.62% represented the highest value recorded as a result of drying skim milk (preheated to 120°C) concentrate (55% total solids) at drier inlet/outlet temperatures of 170°C and 67°C, respectively.* The higher moisture contents were generally associated with a combination of higher preheat temperatures, concentrate solids and lower exhaust air temperatures. A low exhaust air temperature of 67°C indicates the plant's versatility in drying more sensitive products. In general, moisture content rarely reached 4.5% throughout the course of the trials.

Production of Cream powders

Cream powders ranging in fat content from 26-70% fat were prepared by standardising the fat content of a cream-filled skim milk base. Either of 2 process configurations were used depending on fat content:

a) Fat content < 35% fat in dry matter

The typical processing configuration for fat-filled milk powders, whereby fat or cream is blended with a non-fat concentrate base before in-line homogenisation (two-stage: 150/50 bar) while pumping to the drier was adopted for all formulations containing < 35% fat in dry matter. The processing parameters studied included drier inlet temperatures (150; 155°; 160°; 165°; 170°C); atomiser pressure (250 bar); vibrofluidiser No.1 temperature 60°C, and vibrofluidiser No.2 temperature 30°C.

b) Fat content > 35% fat in dry matter

Higher viscosities resulting from the homogenisation of concentrates containing higher total solids (total solids: 46-54%) were overcome by (i) homogenising (2-stage pressures: 150/50 bar) at an earlier stage in the process i.e. after milk fat standardisation and (ii) revising atomiser nozzle sizes. All other process parameters were maintained as outlined in the previous paragraph.

A follow-up study on the production of medium-heat fat-filled powders using coconut oil was undertaken in order to compare the effects of 'filling' skim milk with an unemulsified oil with that of cream on the resulting powder properties. *In general, the physical characteristics of the fat-filled powders were similar to their cream-filled counterparts except for **solubility index** values which tended to be higher (range 0.1-0.6) particularly at the 26-28% fat levels. In addition, **free fat** levels were similar with the two processing approaches.*

It is desirable normally to produce whole milk and fat-filled milk powders with low levels of free fat. Too high a free fat predisposes powder to greater levels of oxidation and contributes to poor rewetting properties during reconstitution later. Homogenisation and spray atomisation help to reduce free fat, and with respect to the latter nozzles are generally better than disc atomisers. Other drying parameters such as operating at relatively high outlet air temperatures tend to promote higher free fat levels. *A comparison between two types of nozzles, sizes 74 and 69, shows (Table 1) that size 69 resulted in a lower free fat (5.9% free fat/g fat) than size 74 when drying a fat-containing concentrate at 46% total solids.*

Atomiser nozzle size affords some flexibility in manipulating exhaust air temperature to give a desired end-product moisture during drying of whole milk powder. For example, applying nozzle size 67 to a concentrate containing 54% total solids enables the drier to operate at a lower outlet temperature of 69°C and not 'over dry' the powder by remaining at higher exhaust temperatures (*Table 1).*

A very satisfactory free fat content of 1.16% free fat/g fat was obtained under these conditions. It was possible to achieve free fat < 1.0% by combining process conditions such as nozzle size 67; concentrate total solids (46-54%); and drier air inlet/outlet temperatures of 165° and 74°C, respectively.

Elevating Free Fat Content

In routine milk powder manufacture, low levels of free fat are desired. However, for certain applications such as chocolate manufacture, powders with high free fat contents are preferred in order to impart better viscosity control during subsequent processing.
A significant development during the project was that the percentage free fat could be largely influenced by the total fat content in the powder as depicted by an almost linear relationship in *Fig.1*. In fact, fat level alone accounted for 96% of the variation.

Other Process and Product interrelationships

Statistical analyses of the results indicate the significance, or otherwise, of various process parameters on % free fat; bulk density and % moisture in *Table 2*. Drier parameters such as inlet air temperature (IT), outlet air temperature (OT) and TS were not significant.

Bulk density was affected by a number of variables both quadratically and interactively: *94% of the variation was due to F^2 (F=fat), IT^2, OT^2, and the interactions between F and TS, TS and IT, IT and OT.*

The interactive effect of % fat and inlet temperature was highly correlated (R_c= 0.91) with moisture content (*Table 2*).

In practical terms, diagrammatic representations (*Figs. 2 & 3*) enable the effect of individual *fat content* on *bulk density* to be identified for a given set of inlet and outlet drier temperatures.

Table 1. Influence of nozzle size on outlet T°C,% moisture and free fat on 26% WMP using concentrate at 54%

Nozzle	%TS	Outlet Temp	% Moisture	% Free fat
74	54	98	1.71	3.47
69	54	90	1.00	3.12
67	54	69	3.10	1.16

Linear inverse relationships which intersected about the mid-axis were established between fat content and bulk density for different drier air inlet temperatures (150°-170°C) when drying cream-filled concentrate containing 50% total solids (*Fig.2*).

The influence of drier outlet temperature on the relationship between fat content and bulk density was inversely linear in the temperature range 70°-74°C (*Fig. 3*). Unlike the influence of inlet air temperature, these lines run parallel to each other.

The type of oil used in fat-filling had an effect on powder properties. Coconut oil was shown to have a positive effect on powder *wettability*. A 14 second *wettability* at 25°C increased to > 60 s when hardened palm kernel oil (HPKO) was used as the replacement fat. *Free fat* content appeared to be also affected by the type of oil used e.g. 0.65% free fat in the case of coconut oil compared with 1.24% for HPKO. Lecithination enhanced both the wettability and dispersibility of the powders produced from both oils.

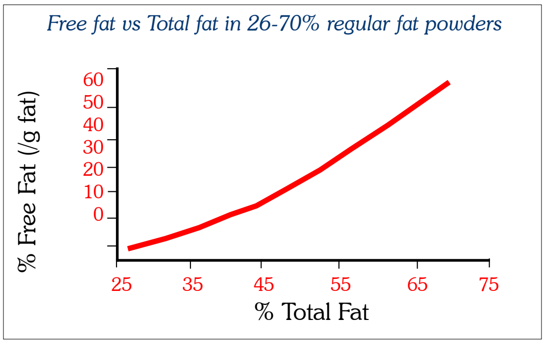

Fig. 1. The Effect of % total fat in powder on % free fat content.

The type of oil used did not significantly affect the coffee stability e.g. coconut oil contributed to a sediment volume of 0.1mL, while the HPKO-based powder was 0.15 mL.

Production of high free fat whole milk powder

A skim milk concentrate base was prepared by evaporation of skim milk, preheated in accordance with the processing conditions necessary to give medium-heat powders. Butteroil was added to the concentrate using gentle agitation, after which it was heated to 80°C and homogenised at low pressures. The free fat levels obtained by this process (*Table 3*) were unacceptably low: two-stage homogenisation at 30/10 bar resulted in higher free fat levels of 14.0% compared with 9.8% for the unhomogenised sample.

Table 3. Influence of zero and moderate homogenisation pressures on the free fat content of butter-oil filled milk powder containing 29% total fat

Regression Analyses of 26-70% Cream-filled powders

Variable constant	% free fat	bulk density	% moisture
F			
TS			
IT			
OT			
F^2	***		
TS^2			
IT^2		**	
OT^2		**	
F x TS		**	
F x IT		***	***
F x OT			
TS x IT		*	
TS x OT			
IT x OT		**	
Adjusted R^2	0.96	0.94	0.91

Table 2. Interrelationships between input variables (fat content; total solids; inlet temp; outlet temp) and powder free fat, bulk density and moisture (significance levels)*

2-stage homogenisation pressure (bar/bar)	Free fat (%) per g fat
none	9.8
15/5	10.7
30/10	14.0

Influence of ***Tinlet*** and varying **Fat** content on **Bulk Density** at 50%TS, OT 72°C and IP 270 Bar

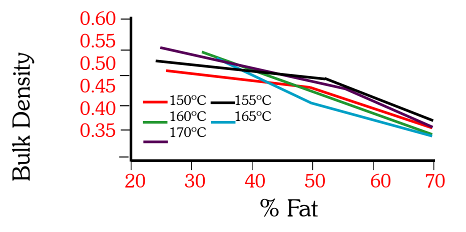

Fig. 2. Interrelationships between fat content and powder bulk density at various drier air outlet temperatures.

An alternative process for the production of high free fat powders was then investigated. This consisted of preparing a high fat base using cream containing 45% fat; standardising with skim milk in order to adjust the fat/dry matter to 70% before concentration (46-48%) and spray drying. The resulting high fat-high free fat powder was dry-blended with skim milk powder in order to standardise downward the fat content to that of whole milk powder i.e. 26% fat. A free-fat level (expressed as a percentage of total fat content) of 82% was obtained. An optional approach for the continuous produtcion of high free fat powder (containing 26% total fat) may be to simultaneously dry-dose skim milk powder into the drier chamber during atomisation of a high fat concentrate.

Development of a milk proteinate ingredient

Influence of ***Toulet*** and varying **Fat** content on **Bulk Density** at 50%TS, OT 165°C and AP 250 Bar

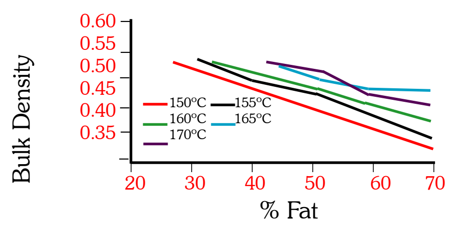

Fig. 3. Interrelationships between fat content and powder bulk density at various drier air inlet temperatures.

Trials were undertaken to develop processes for the production of milk protein concentrate (MPC), Total Milk Proteinate (TMP), Acidified Milk Proteinate (AMP). Applications testing of the ingredients in processed cheese and yoghurt was undertaken, and performances were benchmarked against reference ingredients such as caseinates and yoghurt ingredient blends. Alternative process configurations implemented in the course of commercialising the 'Milk Proteinate' patent proved to be operating successfully in terms of protein recovery. Further validation trials followed, and the emphasis shifted to maximising curd strength in order to facilitate ease of handling during screening, washing and decanter centrifugation later.

The involvement of a specialist process engineering company enabled energy efficient design considerations to be incorporated into an industrial plant that was selected for initial *commercial tests. Having optimised the conditions necessary to produce co-precipitated curd in a form that could be handled with minimal losses, the system appeared to work well in terms of total protein recovery. However, some plant fouling problems were encountered during production. Further studies are being undertaken in order to try and resolve this problem.*

Skim milk powders prepared from milks segregated according to β-lactoglobulin phenotypes

Skim milk powders were produced from milks collected from dairy cows which were segregated according to the β-lactoglobulin (β-lg) phenotypes: AA; AB; BB. Each of the milks were subjected to one of three different preheat treatments (75°C; 8°C; 95°C with holding times of 30 s) prior to evaporation and drying. Whey protein denaturation was monitored throughout processing and in the resulting skim milk powders in order to determine the effects on heat classification of skim milk powder.

It was not possible to establish a relationship between the protein content of milk and β-lg genetic phenotypes. While total protein content was higher in late lactation for all three phenotypes, a comparison of results within one trial reveals that no phenotype could be associated with a particularly high milk protein content. These results mirror the inconsistencies found in published data to date, where widely differing trends are reported. It would appear that variations in the ratios of whey protein/casein for different phenotypes counterbalance each other, resulting in similar total protein levels. The study revealed, however, that higher whey protein levels in milk are associated with the occurrence of the β-lg AA variant. FPLC analyses confirmed that this milk contains higher levels of β-lg and lower levels of α-la than the BB phenotypes.

Analyses of samples taken during manufacture of skim milk powder revealed that the higher level of whey protein associated with β-lg AA was maintained in the undenatured form throughout the manufacturing process. *Thus, if skim milk powder is manufactured from milks containing different β-lg phenotypes under identical processing conditions, the powder containing the AA variant would be expected to contain higher levels of whey protein. This has potentially important implications for the heat classification of the resulting powders, as a higher level of residual undenatured whey protein content in powder will assist in achieving a lower heat classification.* Furthermore, when the percentage decrease in whey protein nitrogen index WPNI (as a result of the preheating step) was considered, it was noted that there was a much greater loss of whey protein for the BB phenotype. This implies that β-lg B denatures at a faster rate than the A variant and will create a bias in the heat classification of powders towards the high heat side because of the lower residual whey protein remaining after heat treatment. Thus, β-lg genetic polymorphism may play a role in powder manufacture particularly where the residual amount and state of denaturation of whey proteins have a bearing on the functionality of end-products.

The AA phenotype of β-lg was also associated with a higher total sulphydryl content of SMP at all preheat temperatures. This is not unexpected since β-lg AA SMP contained higher levels of β-lg. β-lg AA SMP also contained higher absolute levels of slow-reacting SH groups, which suggests that it was less susceptible to heat denaturation. Furthermore, it was found that the AA phenotype powders contained a higher percentage of slow-reacting SH groups (as a percentage of total), which also suggests greater heat resistance for this variant. These findings are in agreement with the conclusion drawn from the WPNI data.

SMP samples produced from milks exposed to higher heat treatments during processing were shown to have lower slow-reacting and total SH contents. This suggests that SH analysis could be used to distinguish between powders that have received different heat treatments. A basis for establishing a correlation between slow-reacting SH content and WPNI values was attempted. Further work is required before the method could be considered sufficiently reliable before putting into general use to augment existing techniques employed to determine the heat classification of milk powders.

Drying sodium caseinate solutions

The influence of total solids and pH on the viscosity of sodium caseinate solutions prior to dehydration on the tall-form drier was also investigated. *The optimum process conditions were identified as 25% total solids at pH 7 and 18% total solids at pH 6.4, followed by preheating to 95-100°C before atomisation.*

Milk Protein Concentrates

Experimentally-produced MPC was evaluated as an ingredient in the manufacture of full-fat cream cheese under commercial conditions. The sensory characteristics and texture of the experimental cheeses were compared to that produced using standard formulations. *Preliminary trials showed that there was no difference in texture and flavour. However, while colour in the experimental cheese was regarded as slightly yellow, it was not regarded as objectionable. There was no evidence of graininess, and whey-off was observed only in the case of a lower protein (70%) MPC.*

Whey Protein Concentrates

A range of whey protein concentrates (WPC) at three protein contents of 35%; 50% and 80% were dried in both regular and agglomerated forms with and without lecithination. Retentates for the drying of WPC-35/50 were produced by ultrafiltration in-house, while that for WPC-80 was sourced in liquid form from a whey processing plant.

Conditions used during drying included:

Retentate solids:	*25-45%*
Drier air inlet temperature:	*165-190°C*
Nozzle atomiser pressure:	*140-290 bar*
No. nozzles:	*3 (reduced to 2 at higher pressures)*

Powder characteristics evaluated:

- moisture content
- bulk density
- protein denaturation

WPC's are generally manufactured to satisfy certain functional characteristics such as gelation and foaming. Because of the globular nature of the proteins, they are particularly susceptible to denaturation during processing, and this may affect functionality. The results show that a certain degree of denaturation arises from the effect of drying at a higher air inlet, as well as an interactive effect from the protein content and total solids (*Table 4*). In other words, high protein retentates are liable to denature more when dried at high total solids content. In overall terms, the amount of denaturation contributed by the drier is negligible relative to that which occurs elsewhere during processing as illustrated by the poor regression coefficient (R^2) of 0.37.

Typical overall denaturation levels of 6.0-26% depending on protein content were observed. Inlet air temperature is clearly linked to the control of moisture content, while protein and to a lesser extent, total solids, are associated with bulk density control.

Table 4. Interrelationships between input variables (protein content; total solids; inlet temp; nozzle pressure) and protein denaturation, bulk density and moisture content.
(significance level)*

Process parameter	Protein denaturation	Moisture (%)	Bulk Density (g/mL)
Constant	10.25	9.81	0.68
protein content (%)			**
total solids (%)	ns		*
Inlet air temp °C	**	***	
Nozzle pressure (bar)			
Protein x total solids	**	*	
Protein x nozzle pr		*	
Inlet temp x nozzle pr			ns
Regression Coefficient (R^2)	**0.37**	**0.82**	**0.87**

Co-drying set-up

The technical feasibility of co-drying, whereby a dry ingredient may be sprayed into the drier chamber by modifying the fines returns system was demonstrated. System calibration showed that it was feasible to achieve dry dosing rates of 1-40 kg/h during spray drying. *The dosing of starch or sodium caseinate as coating agents during the spray drying of fat-filled emulsions proved successful.*

Baking Trials

Baked breads containing high fat milk powder (74% butterfat) achieved higher volume yields (16-18%) and specific yields. The powder showed technological advantages in terms *of being easier to handle, weigh in, and mix with the other ingredients compared to shortening. Also, it did not show a 'melting out' in the proofer that is characteristic of shortening. The dough showed improved machinability and was easier to handle than standard dough.* A slight disadvantage was a negative 'cooked milk' flavour found in the breads after baking. Similar observations were noted during the preparation of sweetcakes using the high fat powder as an ingredient.

Publications

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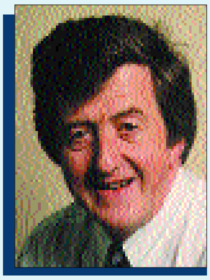

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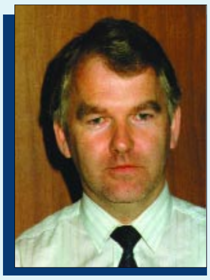

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